

# EOS

## **Crisis on Coral Reefs Linked to Climate Change**

Since 1982, coral reefs worldwide have been subjected to an increased frequency of the phenomenon known as coral bleaching. Bleaching involves the dramatic loss of pigmented, single-celled endosymbiotic algae that live within the gastrodermal cells of a coral host that depends on this relationship for survival. Prior to the 1980s, and as early as the 1920s when coral reef research intensified, localized bleaching events were reported and attributed to factors such as extremely low tides, hurricane damage, torrential rainstorms, freshwater runoff near reefs, or toxic algal blooms [Glynn, 1993]. However, these early occurrences have recently been overshadowed by geographically larger and more frequent bleaching events whose impact has expanded to regional and global proportions.

To underscore the problem, over 60 bleaching events were documented in the period 1979-1990, while there were only three events in 1876-1979 [Williams and Bunkley-Williams, 1990]. A proximate explanation for the occurrence of these events points to meteorological extremes that intensify average summertime seawater temperatures, often in concert with increased penetration of ultraviolet radiation causing both thermal stress and photo-damage to coral tissues [Hoegh-Guldberg, 1999]. A common condition in the timing of these events in the Northern Hemisphere has been the co-occurrence of El Niño-Southern Oscillation (ENSO) events. However, during La Niña, when the northern sectors of the central and eastern Pacific are cooled, surface waters in the subtropical Southern Hemisphere can experience above-average warming at such sites as Easter Island, the Cook Islands, Tahiti, and Fiji [Reynolds and Smith, 1994].

Since 1979, there have been six major bleaching events, all of which were associated with periods of exceptionally warm sea surface temperatures. The observed positive correlation between rising global

temperatures and the occurrence of the two strongest ENSO events in this century leave little doubt that the unprecedented coral bleaching and mortality observed today is linked to climate change.

### **Evidence of Strong La Niña Effect in the Southern Ocean**

ENSO reflects a quasi-periodic reorganization in atmospheric and oceanic water masses leading to relaxation of the easterly trade winds with subsequent westerly wind bursts originating near the International Dateline. These changes, coupled with diminished upwelling, lead to a weakening of the Pacific Cool Tongue and, under very severe ENSO conditions, its complete disappearance. During periods of La Niña, all of these ENSO conditions are reversed and sometimes elevated above average. However, a strong La Niña event in the Northern Hemisphere can result in extreme sea warming in areas south of the equator. The most recent La Niña event, which began in August of 1998, has continued to persist into mid-2000 and has been ranked as one of the seven strongest La Nina events since 1949 [Wolter, 2000].

During a recent visit to Easter Island (27.1°S, 109.3°W) in mid-March of 2000, we surveyed 5 widely distributed coral communities around the island ranging from 3 m to 24 m deep, and observed a large-scale bleaching event in which over 90% of the extant coral colonies of the branching species *Pocillopora verrucosa* had, on average, lost 96% of their endosymbiotic algal populations; such loss usually results in the death of the colony (Figure 1). The percent of bleached corals from counts and line transects taken at five widely distributed sites around the island revealed high levels of bleaching, with an average of 85-90% of the colonies affected down to a depth of 10 m.

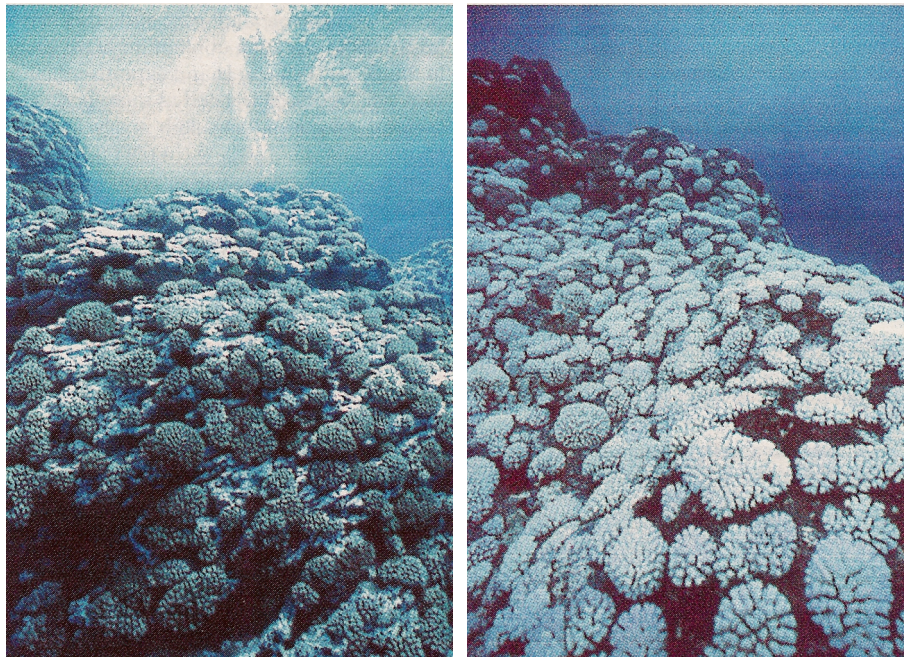
Further, a significant proportion of the extant colonies had recently died prior to our arrival in March 2000, suggesting a connection with the current La Niña event.

Sea surface temperature data derived from an in situ temperature probe deployed at 16-m depth on March 20, 1999, and retrieved March 20, 2000, as well as the Integrated Global Ocean Services System (IGOSS) sea surface temperature data - blended from ship, buoy, and bias-corrected satellite data - revealed that water temperatures began to rise significantly by mid-January. A new predictive tool used to assess bleaching severity, developed by NOAA's Coral Bleaching HotSpot ([http://orbitnet.nesdis.noaa.gov/orad/sub/dhw\\_dhww\\_2m.html](http://orbitnet.nesdis.noaa.gov/orad/sub/dhw_dhww_2m.html)) monitoring program, forecasts coral bleaching when sea surface temperatures exceed expected average summertime maximum temperatures that persist for several weeks. NOAA, in an attempt to use satellite data to accumulate in real-time the thermal stress that corals experience, is using a metric referred to as Degree Heating Week (DHW), which has proven successful in predicting the accumulated thermal stress that corals experience. One DHW unit is equivalent to 1 week of sea surface temperature 1°C above the expected mean summertime maximum.

In the case of Easter Island, where the average maximum seasonal sea surface temperature is 25.1°C, temperatures at or above 26.1°C could result in bleaching. Bleaching HotSpot charts have been produced by NOAA since 1997 and provide early warning for the onset of bleaching events worldwide.

DHWs are being tested as an attempt to provide a measure of bleaching severity that may lead to mortality from accumulated thermal stress. For example, two DHWs would describe 1 week of temperatures above 2°C or two weeks 1°C above the expected mean summertime maximum. Based on empirical observations at other sites, DHWs of 10 or more weeks have been accompanied by severe coral bleaching and often mortality. At Easter Island, both the in situ temperature probe and satellite data were consistent in reporting sea surface temperatures that resulted in an accumulation of 9-10 weeks of

degree heating, sufficient to cause severe bleaching (Figures 2 and 3). The extremely low levels of the endosymbiotic zooxanthellae found in the bleached corals is consistent with the prediction.



*Fig. 1. Colonies of Pocillopora verrucosa at 10-m depth near Hanga Roa, Easter Island (Rapa Nui). The photograph on the left (March 18, 1999) shows healthy zooxanthellae pigmented colonies; on the right (March 14, 2000) virtually all coral colonies are bleached after exposure to several weeks of exceptionally high sea surface temperatures. The whitened appearance indicates the absence of symbiotic algae in the coral tissues.*

Only one other bleaching event had been reported at Easter Island. In June 1980, a mass expulsion of zooxanthellae took place at Easter Island. This event was attributed to torrential rainfall that led to bleaching as a result of lower salinities and osmotic stress to the coral [Egaña and DiSalvo, 1982]. Unfortunately, no quantitative data were collected that would have provided a valid comparison between the two events. Qualitative observations and statements from long-time residents, however, do suggest that the 1980 bleaching event was much less severe than the 2000 event based on the following comments by Egaña and DiSalvo "white corals occurred in patchy, discontinuous zones." In addition, local divers, some of whom were 80 years old at the time, were interviewed by Egaña and DiSalvo and consistently stated that such an event had not been witnessed previously. Also, Egaña and DiSalvo did report that full recovery was achieved within 2-3 months after the event - an outcome quite different from that witnessed in 2000.

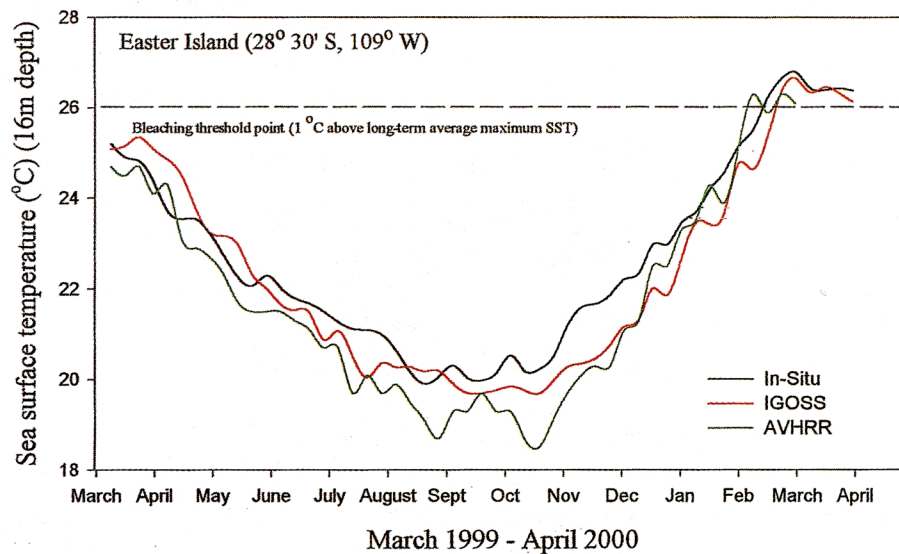


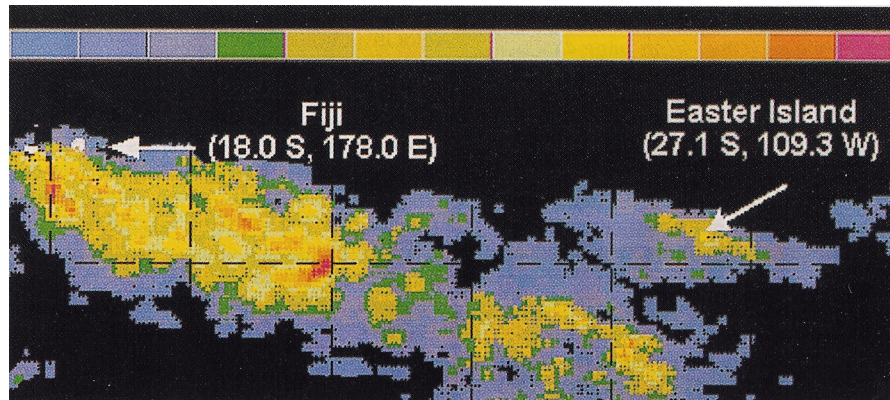
Fig. 2. Plot of sea surface temperature data at Easter Island from March 1999 to April 2000 based on three sources of data: in-situ temperature probe (black line) at 16-m depth; Integrated Global Ocean Services System Products Bulletin (IGOSS, red line); and Advanced Very High Resolution Radiometry (AVHRR, green line).

Among the corals that had bleached, which includes both branching and massive colony morphologies, a follow-up survey conducted at Easter Island in October 2000 verified the prediction that coral mortality would be high. An average of 85% of the branching corals (*Pocillopora verrucosa*) between 0 m and 10 m depth, in the zone of highest coral cover, are now completely dead. In addition, algae is growing over their skeletons. The less abundant massive coral, *Porites lobata*, representing about 5% of the total coral fauna, appear to have survived the thermal stress.

Concurrent with the bleaching event at Easter Island, reefs in Fiji, further to the west at 18°S, also experienced severe thermal bleaching for the very first time and also reported moderate to high levels of mortality (Figure 3).

Will these reefs recover? The answer to this question depends on the frequency of future warming events and whether the surviving coral colonies are sufficiently resistant to higher water temperatures. The ability of corals to tolerate or adapt via selection to rapid environmental change is the key question facing reef researchers. Laboratory and field experiments are currently underway to address this question.





*Fig. 3. Composite image showing the accumulation and distribution of sea surface temperatures occurring above the long-term summer average at Easter Island and Fiji on March 21, 2000. Scale represents the number of "degree weeks" above normal high temperatures. Each color block in the scale represents, left to right, a successive week in a 13-week period of increasing warming; i.e., the left-most block represents week 1 and the right-most block represents week 13. At this time, Easter Island had accrued 9 degree weeks, which is sufficient to cause severe bleaching with high rates of mortality. Sea surface temperatures were determined by Advanced Very High Resolution Radiometry (AVHRR).*

## Link to Climate Change

Are coral bleaching and accompanying mortality resulting from anomalously high SSTs a recent phenomenon? Does any evidence link these perturbations to global warming? Although the first thermal bleaching event recorded in the Caribbean was in 1987, no such bleaching events had ever been reported in Belize until 1995.

However, during the 1997-1998 ENSO, massive bleaching occurred along the entire length of the largest barrier reef in the Northern Hemisphere. Aronson et al. [2000] recently reported 100% mortality of once-abundant coral stands in the lagoonal shoal reef habitat. To date, there has been no coral recovery at this site. A well-established sponge community has quickly overgrown the dead coral skeletons and is likely to prevent coral recruits from gaining a foothold in the foreseeable future. Reef cores retrieved from these sites revealed continuous coral growth as far back as 3000 years B.P. It appears that massive coral mortality such as that observed in 2000 has not occurred in Belize over the past 3 millennia.

Other evidence suggests that ENSOs occurred less frequently in the past. For example, a 400-year-long coral record collected at the "epicenter" of ENSO activity in the Galápagos Islands, indicates that in the mid-1600s, the frequency of ENSO progressively increased in a step-wise manner following the end of the Little Ice Age [Dunbar et al., 1994]. In the mid-1600s, the recurrence interval was centered at one event every 6 years. By 1750, the frequency increased to 4.6 years and by the mid-1800s, the pace

stepped up to one event every 3.4 years, close to the present rate. These data clearly indicate that the spacing of past ENSO intervals has not been driven by anthropogenic influences.

However, we know little about how fossil fuel burning since the beginning of the Industrial Era may have influenced the magnitude of the most recent ENSOs. The past two severe El Niño events set record-breaking global temperatures. In a recent analysis by Karl et al. [2000], it has been noted that paleoclimate studies, extending back hundreds to thousands of years, indicate that the 20th century is warmer than any other period over the past 500 years or longer. Perhaps most alarming is that recent warming over the past couple of decades has already reached levels that were predicted to occur during the 21st century [Kattenberg et al., 1996].

Current severe, thermally-driven disturbances to coral reefs worldwide do not bode well for the future health of this ecosystem, particularly if genetic responses are unable to keep pace with an increasing frequency and/or magnitude of ENSO/La Niña activity.

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